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Compatibility Evaluation of Point Clouds Acquired with Terrestrial and Mobile LiDAR Scanners

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***Abstract*— *Light Detection And Ranging (LiDAR) is a technology that arose in the last years as one of the best technologies to capture tridimensional information about features on the Earth´s surface. LiDAR measurements can be carried out over the ground in a static mode, with the scanner fixed on a tripod. This mode is known as Terrestrial LiDAR. LiDAR measurements can also be acquired in a kinematic mode when the scanner is assembled and transported on aircrafts, cars, boats and even in special vehicles that operate in underground mines and galleries. That second mode is called Mobile LiDAR where the LiDAR scanneris connected to an Inertial Navigation System (INS) and a dual frequency GNSS receiver that respectively provide the orientation and the position of a platform and consequently the direct georeferencing. This paper focus is to compare results obtained from data collected over the same area in both scanner modes but with uncertainties. This study has used both terrestrial and mobile LiDAR scanners to generate a 3D model of the terrain of a chosen area and to calculate the volume above a predefined reference plane. The same volume was estimated with a conventional topographic technique that uses collected points in the same area using RTK - GNSS receivers.*

***Keywords*— Point Cloud, LIDAR Technology, Terrestrial Scanner, Mobile Scanner, GNSS.**

I. INTRODUCTION

In the last decade the large offer of new technologies for mapping, like the Light Detection and Ranging (LiDAR) and the Unmanned Aerial Vehicle (UAV), or drones, for example, made the geoscience studies advance to limits not totally explored before.

Whether the cost of the instruments or the lack of specialized professionals, the fact is that these two technologies are not being used as everyday tools and still deserve studies and research to better define their areas of application.

Despite that, these technologies can certainly be applied to Civil Engineering and Transportation Engineering, particularly to road and railroad design and construction. The study presented in this article is to better know and exploit the LiDAR technology.

LiDAR scanners have the ability to provide detailed information on the benefits of the project, its construction and its management.

One LiDAR scanner can measure a large amount of points in a short period of time which means the 3D environment can be quickly captured and analyzed [1]. The concept behind the LiDAR scanner measurement is similar to the total station measurement. The 3D position of a certain point is defined by the bearing and distance from the scanner that has its position georeferenced.

In a simple way, we can say the azimuth that goes from the LiDAR scanner to a certain point is defined in function of the scanner intern orientation. The distance for each 3D point is measured in a similar way like used in GNSS positioning measurements. One beam of light after trigged reflects on the point and returns to scanner giving the distance in function of the time of beam of light propagation. Once the LiDAR scanner has a known position the measured point position can be acquired by vector calculation.

Some LiDAR scanners measure distances using the phase shift technique [2], comparing the returning wave to the trigged one in the beam light to obtain the time difference or the wave travelling time. The phase shift technique relies on modulating the amplitude of the light emitted and measuring the phase difference between the emitted light and the received light. Once the phase

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difference, the modulation, frequency (*f*) and the speed of light (*c*)is known the distance can be estimated as follows:

$$d = c\frac{t}{2} = c\frac{\Delta\phi}{4\pi f}$$

This kind of scanner can measure over 100,000 points per second with precision of 1 millimeter.

Other LiDAR scanners measure the distances using a pulsing beam of light performing the called pulsed time offlight technique [2]. In this case, the scanner emits short groups of light beam and measure their returning time to itself, so as to acquire the distances. This kind of scanner can measures up to 50,000 points per second with precision ranging from 3 to 6 millimeters.

1.1 Point Cloud Capture

When using the LiDAR technology we must well define the job goals to properly choose the scanner and the method to acquire the 3D points. In a simple way, there are two types of scanners, the called Terrestrial LiDAR scanner(TLS) which works in static mode in certain positions and the Mobile LiDAR scanner (MLS) that works in a kinematic mode, being transported by any kind of moving vehicle, like car, plane or boat.

Different methods offer different ways [3] to do the measurements that best suit specific and different tasks. The type of scanner that uses the phase shift technique is indicated to be used in indoor tasks, or in small areas due to the range limitations and the generation of multiple capture files necessary to cover the area without occlusion zones. Several files produced in the same job must be digitally linked to each other, so as to connect them, and to do that, it is common to use spheres or other kind of targets that must appear in at least two adjacent capturedscans, which demands a previous study over the place to be captured to define their positions. This type of scanner is better suited for tasks where the capture of details is more important than the covering speed.

When working in a job where the quick covering of large areas is necessary and the detail accuracy is less important, the the pulsing beam of lightscanner type is more indicated.

1.2 3D Environment

The knowledge about the environment has always been an important and fundamental support for the engineering tasks, but it is very hard to be produced. Even using advanced techniques such as topography of precision, that uses the top model instruments, like the robotic total station and the GNSS real time kinematic method (RTK), the production of digital terrain model (DTM), for example, is a costly task, and require long period of measurements.

With the advent of LiDAR scanners that can be carried by hand or in small vehicles the capture of the environment details has become simpler and faster.

The Faro X130, a TLS that uses phase shift technique to perform the point cloud capture, is being able to measure from 122,000 to 976,000 points per second and achieving $\pm$ 2 mm precision for each measured point[4]. It has an integrated GPS receiver that works in real time. When linked to a GNSS external network, it gives a coordinate system to be used by the scanner. Due to its limitation in range, up to 130 meters, the scanner must be moved to different scan positions to insure a full coverage of an area that is bigger than its range limitations.Figure 1 shows two locations, one indoor and the other outdoor, where the Faro X130 TLS scanner was used.

Fig.1: Faro X130 TLS Scanner

The files produced in each scanner's position denote a session of capture or scan, and one job can have several scans if the area to cover is too big.

The Trimble MX2 is a Mobile LiDAR scanner that allows the acquisition of point clouds on a moving platform. It has one rotating head connected to two GNSS antennas, one inertial navigation system (INS) and one high resolution panoramic camera, forming a complex navigation system [5] that can be assembled ontop of a sport utility vehicle (SUV). Figure 2 shows a single-head MX2 MLS system.

Fig.2: Trimble MX2 MLS Scanner

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The GNSS receiver and the INSunit are controlled by a robust laptop inside the vehicle to constantly acquire data using the LV-PosView software[6].

II. MATERIALS: STUDY AREA AND DATA-SETS

The creation of a sample data-set that would allow the comparison of two or more point clouds acquired with the use of a Terrestrial LiDAR Scanner (TLS) anda Mobile LiDAR Scanner (MLS) was carried out. In addition to the compatibility analysis done by comparing point clouds acquired by both LiDAR technologies we also used a reliable conventional measurement technology well recognized in engineering jobs, the RTK GNSS, to measure several points in the same surface.

Some field activities were carried out on Laval University campus where an area with sufficient relief to be analyzed is present.

Fig.3: Chosen site for the Case Study.

That area shows enough vertical variations to be studied and to facilitate the operation of both TLS and MLS LiDAR scanners.

The selected area should offer the vehicle which carries the MLS scanner, a path to cover thefull area. The area should not be too large to be surveyed by the TLS using a reasonable number of scans consideringits range limitations ofaround 130 meters.

The vegetation over the surface has also been taken into account by the point cloud processing software in order to classify points on the ground and the points in the trees to separate classes before computing the volume.

After a field inspection we found an area that fulfills the predefined conditions. It is located in front of the Pavillon Louis-Jacques-Casault, along the bikeway, as shown in Figure 3.

This area is around 100 meters long, 30 meters wide and 3 meters high. Because it is surrounded by paved streets and its limits are well defined by sidewalks and gutters, the MLS can easily circulate around this area.

The first dataset was acquiredwith the Faro X130 TLS. This scanner produces point clouds with high density which means that more measured points per volume unit considered. To cover the chosen areaof this project using this TLSscanner, four scanning sessions were necessaryas shown in Figure 4.

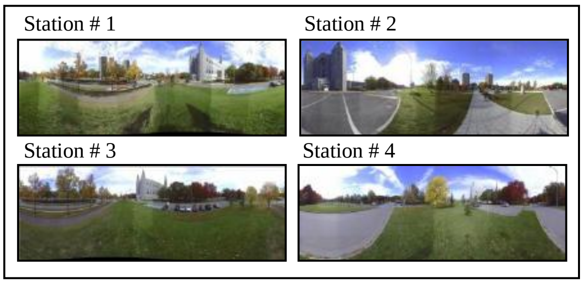

Figure 4: Terrestrial Faro X130 scanner Capture Stations.

The positions where the TLS wasinstalledwere carefully chosen to avoid occlusions, areas produced by objects that block the laser beam, forcing its return to scanner and hiding what is behind that object.

After the scanning process, each point cloud is an independent file with its own coordinates system. Because of that, they had to be assembled into one point cloud representing the total scanned area in the same coordinate system, as seen in Figure 5. Thisadjustment process, called registration, uses points clearly identified that appear in two or more point clouds. In this project, 10 spheres of 139 millimeter diameter were used. These spheres are white to enhance the laser beam reflection and to provide its clear identification in different point clouds. The spheres were properly positioned in the field between two consecutives stations, at different elevations to avoid the coplanar condition that would makethe adjustment to fail.

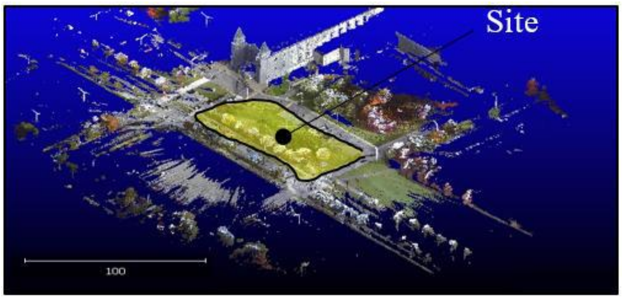

Fig.5: TLM Point Cloud Generated.

Although the TLS has an integrated GPS receiver, it was disable because it is not necessary to perform the "cloud to cloud" registration that allows one point cloud to be aligned using other geo referenced point cloud as reference.

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The second capture of the same area was made using the MX2 MLS carried by a SUV vehicle.

The collected point cloud of the project area and its neighborhoodis shown in the Figure 6. The wide scanning range of MX2 scanner can capture points farther from the interest area while the vehicle was moving on the Avenue du Séminaire and the Rue des Arts covering the façades of the Pavillon Louis Jacques Casault and the Pavillon Félix-Antoine Savard located about 200 m apart.

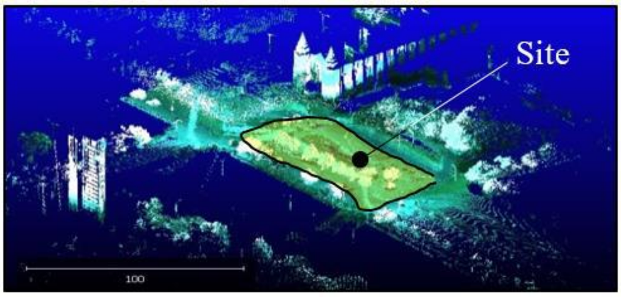

Fig.6: MLS Point Cloud Generated.

Both TLS and MLS scanners are able to define a georeferenced coordinate system to support the collected point clouds. However, point clouds acquired with the TLS scanner were referred to a intern local system of coordinates and further converted to the geo referenced coordinate system of the MLS data.

The TLS point cloud was aligned to the MLS point cloud using well defined common points and was integrated to the MLS geo referenced coordinate system to assure that the segmentation process produces two surfaces with the same limits.

After the data acquisition using the both LiDAR technologies, the same area was available in two different point clouds of different density. The TLS scanner produced four point cloud files and a total of 73,779,252 points and the MLS scanner generated one file with 3,773,500 points. The covered area and the point density being different in point clouds collected by both systems, some editing tasks must be carried out to prepare and isolate the surface of interest on which we need to estimate the volume.

To balance the density of both point clouds, the TLS points were subsampled by reducing its number of points while retaining a representative content of the original cloud. In addition to the resolution, each point cloud had to be analyzed before comparing them.

For instance, the common area of interest must be extracted from the original point clouds. The segmentation tool, available in most LiDAR processing software is normally is used to carry out some cuts in the point cloud and extract the area of interest. It is a tool similar to the cropping tool available in image processing software (e.g. Photoshop) with the fundamental difference that the point cloud segmentation tool works in the tridimensional space.

After subsampling and segmenting both clouds, the TLS interest area was reduced to 7,563,870 points and the corresponding MLS one to295,627 points as shown in Figure 7.

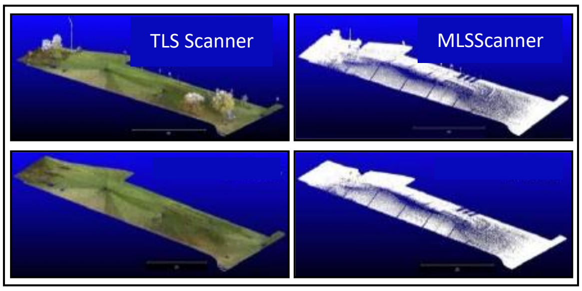

Fig.7: Point Clouds Edition.

The software ability to discern multiple return pulses [7] not always is a hundred percent achieved and because of that another task that needed to be done before calculating the volume of the interest surface area. The removal of noise features like trees, traffic signs and electrical power poles, for example must be done. This kind of cleaning can be manually done which takes a considerable amount of time and presents some risks of affecting the surface coverage. Another way to clean the surface is to use filters available within the point cloud processing software. In this study, the *Cloth Simulation Filter* (CSF) [8], available in the *Cloud Compare* software was applied and produced a good result, as can be seen in Figure7. The two images at the top contain point clouds with the aforementioned noise features and the two bottom images the cleaned point clouds. The CSF is a computer graphics algorithm that identifies a surface that is under a vegetation coverage by inverting the point cloud and analyzing the points that represent the ground. As a result, the CSF can separate point clouds into ground and non-ground points. To execute this task the original point cloud should be exported to LAS file [9].

Once both surfaces have been well aligned and correctly segmented, meaning to say with the same limits and free of noises, like trees, traffic signs and other features, their volumes were calculated above the reference plane estimate dat the altitude of 85.013m, passing through the lowest altimetric point in the cloud. Two point clouds software packages were used to calculate the volumes that are presented in table 1.

Table 1: Calculated Volumes

LIDAR Scanner	RealWorks (m^3)	CloudCompare (m^3)
TLS	2,312	2,337
MLS	2,284	994

The comparison between the volumes calculated using the TLS data by these two software show adifference of 1.08%,what can be considered as a compatible result. However the MLS volumes calculated with the MLS data could not be compared because of a remarkable difference obtained with *Cloud Compare* software probably produced by in the presence of outliers. The volume calculated by *Real Works* with th MLS data resulted different in 1.20%.

Therefore, these results would need to be validated outside the LiDAR universe, using a conventional and recognized technology to assure the reliability of the result.

III. VOLUME VALIDATION

To validate the volumes obtained using the point clouds measured with TLS and MLS scanners, the selected surface was also measured using a GNSS-RTK receiver providing a classical and reliable measurement solution. The volume measurement using the Real Time Kinematic (RTK) method[10] was actually taken as reference to do the final analyses and comparison with respect to the volumes obtained with point clouds collected using the LiDAR technologies presented in the previous section.

The perimeter and all interest points inside this area necessary to properly model the surface were measured using Trimble R8S GNSS-RTK receiver. A total amount of 381 3D points were measured with this technology in order to cover the full surface of the interest area.

Three volume calculation methods that use the points measured inside the area and on its perimeter were tested.

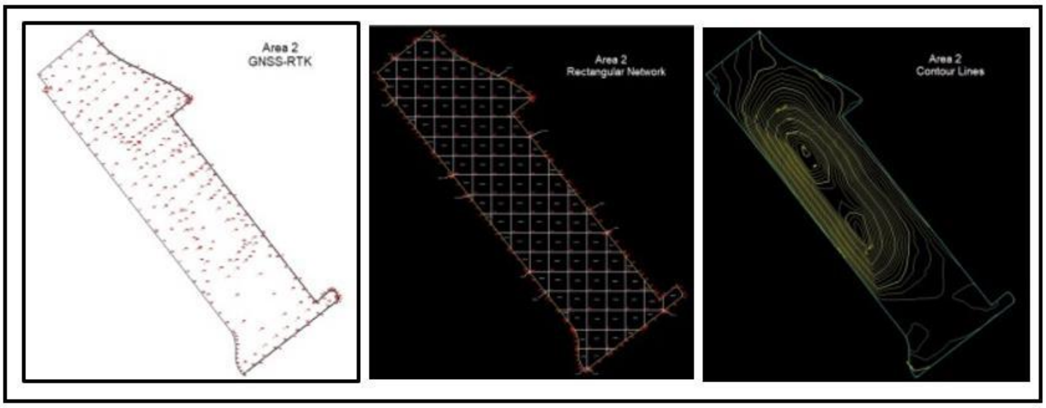

Fig.8: Volumes using GNSS - RTK

The first method of volume calculation was to usethe Bentley Topograph software that generates the Digital Terrain Model (DTM) from the RTK points[11]. The horizontal reference plane was considered passing through the same vertical point adopted in point cloud calculations, meaning to say at the altitude 85.013 m. The calculated volume between the generated surface and the horizontal reference plane was 2,392 m^3.

The second method of volume calculation was to use the weighted heights method that subdivides the surface into several prismsof regular areato calculate the volume inside them using the mean height of its vertices, with the following equation:

$$V = \frac{1}{4} \times (\Sigma_1 + 2 \times \Sigma_2 + 3 \times \Sigma_3 + 4 \times \Sigma_4) \times Q$$

In this equation the sum indexes (1, 2, 3 and 4) indicate how many times each vertexis connected to adjacent prismsand Q represents the area of the prism.

In thisequation, the total volume is given by the sum of the individual volume for each prism. In this case, the RTK points were used to assemble the rectangular network with 122 quadricules (or prisms), necessary to apply the method. Mostof these quadricules were regularly squared (5m x 5m). Some irregular quadricules (fractional) followed the same method, but were calculated individually. The horizontal reference to calculate the heights was also the same plane used before, at an altitude of 85.013 m, going through the lowest point in the surface. Each prism above that plane was calculated using the Microsoft Excel software by applying the Gauss method to determine the quadricule area and the mean height from the involved points to calculate the volume. The obtained volume with this process was 2,284 m^3.

The third method was calculated from the contour lines, where the area (*S*) inside each contour line is multiplied by the vertical spacing (*d*)between them to get the volume, as follow:

$$V=\left(\frac{S1}{2}+S2+S3+\cdots+\frac{Sn}{2}\right)\times d$$

The contour lines used in this method were generated from a DTM created in the first method, spaced by 10 cm (d= 0.10m). The total vertical distance from the lowest point to the highest in the areais 3.08 meters, from 85.013 m to 88.061m altitude, in which interval 30 contour lines were inserted. The volumes obtained in each method are presented below.

Table 2: Volumes using Conventional Technology

Method	Area (m^2)	Volume (m^3)
1. DTM	2,178	2,392
2. MeanHeight	2,178	2,284
3. ContourLines	2,178	2,298

In function of these results we assumed the mean volume equal to 2,325 m^3 as reference to validate the four volumes previously calculated using the point clouds, and, to produce the differences as seen in the table 3.

Table 3: Point Cloud Volumes Differences.

LiDAR Scanner	Real Works (m^3)	Cloud Compare (m^3)	Differences (%)	
TLS	-13.29	11.68	+ 0.88	+ 1.97
MLS	-41.06	N/A	- 0,33	N/A

The LiDAR estimated volumes are comparable to the volumes computed using the conventional RTK technology. As mentioned in the previous section, the volume calculated with MLS data using the *Cloud Compare* software was different than the volume calculated with the same data using *Real Works* and the volumes computed by the TLS data. That very large difference deserves an extra analysis in order to understand the reason of the problem.

IV. CONCLUSIONS

The above experiment has demonstrated that the LiDAR technology is reliable to carry out volume calculation for engineering purposes.

After a careful preparation of point clouds collected with a TLS and a MLS scanners to isolate the same interest surface, *RealWorks* and *Cloud Compare* softwares packages have been used to estimate volumes with both software and evaluate the reliability of the results.

However, the volume computed by the processing of the MLS data with *CloudCompare* software was different than volumes computed by other techniques and datasets. A deeper analysis must be carried out to evaluate the cause of this problem.

The lower density of point cloud collected with MLS with respect to those collected with TLS is not the main cause because a reliable volume value was obtained by the *RealWorks* software. Therefore, we must investigate how *CloudCompare* is handling the point cloud to obtain the volume. Finally, this case study is probable not enough to definitively make final conclusions. It is necessary to increase the number of case studies that would consider larger areas, bigger vertical distances and more irregular terrains.

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